AN INCREASE IN LOWER EXTREMITY INJURY AS A RESULT OF COGNITIVE AND PSYCHOLOGICAL DEFECITS OF CONCUSSION

by

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July, 2021

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Purpose: Sport-related concussions have shown to have effects on self-efficacy, oculomotor performance, reaction time and an increased risk of lower extremity injury. Most studies have been conducted to test the effects of acute concussions in athletes and not on long-term effects. Researchers have been able to test these effects using neuroimaging and physical testing to test the differences between concussed and non-concussed athletes. To understand the relationship between concussions and its effects on lower extremity risk it is important to be able to understand what is going on cognitively and psychologically in concussed athletes and to be able to detect what factors are remaining long-term. These factors could indicate the reason why lower extremity injuries are associated with sport-related concussions and how they can be treated or maintained to limit the incidence of lower extremity injury. **Methods:** Aim 1: Participants who were current athletes completed an online survey to measure their self-efficacy relative to their sport after they had been cleared to return-to-play following a concussive injury. This aim did not use a control group. Aim 2: Participants completed two surveys on their history of concussion and their history of lower extremity injury. All participants (concussed group and control group) then completed a virtual GO/NO-GO task that was presented in a Tobii HTC VIVE Pro Eye virtual reality eye tracking enabled headset that measured oculomotor performance. Participants were asked to wear a G-Tec (500 Hz) 32 channel EEG cap to measure reaction time while they perform the necessary tasks **Results:** Objective 1: Participants (N=9) were involved in collegiate, club, or recreational sports with at least one sport related concussion within a two-year period and had a mean age of 20.56 ± 1.74 years. Confidence about returning to play was reported in 11.9% of the participants. The mean scores for question #13 on the survey indicated that participants had low levels of self-efficacy when returning-to-play.

Objective 2: Participants (N=25) included five concussed participants who are currently involved in basketball (20%), volleyball (20%), rugby (20%), soccer (20%), and marching band (20%). The control group consisted of twenty participants with a mean age of 21.24 ± 2.803 years consisting of 30% currently involved in rugby (50%), dance (16.67%), frisbee (16.67%), and softball (16.67%). There was not a statistically significant correlation between concussion and lower extremity injury. There was no statistically significant difference saccadic eye movement reaction time during the task. A comparison of channel spectra indicated statistically significant differences ($p<.05$) in frequency bans across channels in the frontal and parietal regions of the brain as well as statistically significant ($p<.05$) changes in ERD and ERS in frequency bands of the left frontal, right frontal, and parietal regions between the groups. **Conclusion:** The results of this study suggest that cognitive and psychological effects due to concussion could produce an increased risk for lower extremity injury in athletes. While the correlation between report of concussion and report of lower extremity injury was not significant, it is clear the long-term effects of concussions are affecting athletes negatively and are causing differences in reaction time and self-efficacy. Since sports demand high levels of attention, confidence, and decision-making, concussed athletes that return-to-play too soon from a concussive injury may not have sufficient cognitive and psychological resources to operate appropriately during sport events, and thus may be at higher risk of further injury.

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A Thesis

Presented to the Faculty of the Department of Kinesiology

East Carolina University

In Partial Fulfillment of the Requirements for the degree

The Master of Science in Kinesiology

Sport and Exercise Psychology Option

by

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July, 2021

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Chapter I. Introduction

Approximately 1.6 to 3.8 million concussions occur in America each year due to competitiveness in sports activities (Daneshvar, Nowinski, Mckee & Cantu, 2011). Sport-related concussions have become a prominent part of our society and much of the research has focused on the immediate impact of a concussion and factors that influence return to play; however, little research has focused on the long-term (>6 months) consequences of concussion. Sports-related concussions occur in approximately 21% of college athletes with implications for long-term cognitive impairments including working memory (Hudac, Cortesa, Ledwidge & Molfese, 2017). Working memory is used for reasoning and decision-making which are important variables in high-contact sport settings. Impairments in these types of brain functions can cause athletes to underperform and potentially be put in risky situations that can lead to further injury. Long-term consequences of concussion are not well understood because the field has only recently begun to grow for research purposes. With the absence of a diagnostic test or biomarker, diagnosis of concussions is reliant on self-reporting symptoms. This lack of testing is not ideal to rely on as a sole marker as many symptoms can go undetected without proper testing. The use of multiple assessment tools increases the specificity of diagnosis and provides a basis for return-to-play. Recently, researchers found that concussions may produce lasting negative consequences even after acute post-concussion symptoms have resolved (McGowan et al., 2019). These long-term effects include a change in cognitive functions and motor performance. Concussions have shown to leave disruptions in areas of the brain such as slowed reaction time, oculomotor performance, and self-efficacy for months to even years after the injury has occurred (Beaulieu et al., 2019). With an increased risk of long-term effects on motor performance, the likelihood of daily disruptions of motor performance becomes more prominent. Participating in contact sports involves a large emphasis on large muscle group movements in lower extremities. These movements are based on decision-making processes and reaction time during game time settings. Impaired individuals are slower to respond to and are less accurate in tracking visual stimuli (DiCesare, Kiefer, Nalepka & Myer, 2017). With the ever-changing environmental demands associated with sport participation, altered visuomotor processing may also negatively impact task performance, modifying injury risk as well (Herman et al., 2016). Delays in these types of cognitive functions can lead to athletes facing risky or dangerous situations during their performance due to not being able to perform necessary movement tasks appropriately in times that are critical to performance or safe execution of a performance task. This could lead down a path of a higher frequency of lower extremity injuries in those with these types of deficits.

Even though it is not clear why, research has found a relationship between concussion and lower extremity injury. Recent studies consistently report an increased risk of 1.6 to 2.9 times for lower extremity injury during sport participation following a concussion (Gilbert, Burdette, Joyner, Llewellyn & Buckley, 2016). This risk could be associated with neuromuscular and neurocognitive deficits. The increased injury risk following concussions suggests that routine care does not fully capture persistent neuromuscular and neurocognitive deficits associated with lower muscular injury (Herman et al., 2017). To further investigate solutions for this problem research must be done to explain why this increase is occurring in concussed athletes as opposed to non-concussed athletes and what factors increase the risk of lower extremity injuries in sports.

Purpose

The fundamental purpose of this research proposal is to show that physical and psychological effects of concussion cause negative symptoms on those inflicted that result in a higher risk of lower extremity injury. Mainly the research will investigate reaction time, oculomotor performance, self-efficacy, and the presence of lower extremity injury in a concussed population in comparison to a control population. Many studies have been conducted to test the effects of concussions on athletes in contact sports. Although little has been done concerning the long-term effects (>3 months) of concussions on brain function and motor control, research has shown a strong relationship between lower extremity injury as a result of at least one concussion in contact sport athletes. Direct assessment of neuromuscular and neurocognitive processing over time is needed to fully understand persistent deficits in reaction time, oculomotor performance, and self-efficacy, and their effect on risk of lower extremity injury. Thus, the study will investigate two aims to evaluate these deficits. Aim 1 will measure self-efficacy only in athletes who have returned-to-play following a concussive injury with no control group. Aim 2 will assess and compare oculomotor performance and reaction time in a control group and a concussed group. Understanding these relationships could help change the way we treat those who receive this damaging injury and help prevent lower extremity injury by creating specific protocols that can detect long-term effects of concussion.

Hypothesis

The first hypothesis is athletes who have received at least one concussion during their sport will indicate low levels of self-efficacy. The second hypothesis is athletes who have received at least one concussion during their sport will indicate slower reaction time and a decrease in oculomotor performance when compared to the control group. The third hypothesis will show a positive relationship between reaction time, oculomotor performance, self-efficacy, and the presence of lower extremity injury risk in concussed participants. These hypotheses will help to further the knowledge of the occurrence of lower extremity injury as a consequence of concussions as well as possible reasons as to why there is an occurrence of lower extremity injury.

Delimitations and Limitations

This study creates a risk of delimitations due to its constraints. The nature of sports creates a delimitation for this study as well since they often facilitate high occurrence of injuries. This could cause non-concussed athletes to have a higher frequency of lower-extremity injury and thus creates less significant differences between concussed and non-concussed groups in relation to lower extremity injury. The limitations of the current study include the ability to recruit athletes who have received both a concussion and a lower extremity injury within the past two years that are involved in a variety of sports.

Chapter II. Review of Literature

Introduction

Sport-related concussions have been found to leave lasting effects on reaction time, oculomotor performance, self-efficacy, and increase the risk of lower extremity injury. Most studies have been conducted to test the effects of acute concussions in athletes and not on long-term effects. Researchers have been able to test these effects using neuroimaging and physical testing to test the differences between concussed and non-concussed athletes. To understand the relationship between concussions and its effects on lower extremity risk it is important to be able to understand what is going on cognitively and psychologically in concussed athletes and to be able to detect what factors are remaining long-term. These factors could indicate why lower extremity injuries are associated with sport-related concussions and how they can be treated or maintained to limit the incidence of lower extremity injury.

Oculomotor Performance

The ability to recognize the presence of a hazard is directly linked to our ability to fix our gaze on a target, recognize the threat, and implement a plan of action (Dana-Dos-Santos et al., 2018). Tracking objects in the environment is vital for athletes to interact with their surroundings during sport activities in order to properly produce movements and avoid a risky situation. Some research has shown that there are clear differences in eye-tracking between concussed and non-concussed athletes. The differences in eye-tracking can also be related to attention and focus and how these factors are affected as well. Three of the seven oculomotor tasks (antisaccade, self-paced saccade, and memory-guided saccade) that have been tested on athletes have showed significant differences between the recently concussed group compared with non-concussed individuals (Johnson, Hallett & Slobounov, 2015). Concussed participants showed a 40 ms lag while completing an antisaccade task, which consisted of participants looking in the opposite direction of a target, and then showed an increase to a 15 ms lag after 30 days post-injury. Self-paced saccades, which consisted of participants looking back and forth between two targets are quickly and accurately as possible, increased from 65-80 ms. Memory-guided saccades, which consisted of a participant repeating a memorized sequence once a target moved three times in one sequence, showed improvement from 3.5 to 1.5 reduction in directional and position errors from initial testing (Johnson, Hallett & Slobounov, 2015). In the quick changing environment that athletes compete in there is little to no time for delay without repercussion. These tracking delays could lead an athlete into a situation of increased risk of injury that could include collision with another player or with the object used to play the sport.

Fixation of the eyes can be examined to measure the attention and focus of subjects during a variety of tasks. Attention and focus during athletic participation are a primary factor for proper execution of athletic performance. Concussed individuals proved to be less accurate in their fixations and indicated a diminished saccade performance, which detects their capability of attending to important objects (DiCesar et al., 2017). They were significantly less accurate while fixating on a target between saccades and exhibited impaired performance in tracking a target along a predictable path compared to the healthy controls during eye-tracking tasks (DiCesare et al., 2017). Being able to properly attend to objects during play is expected during play for healthy individuals when they reach a higher level of sport. These athletes are also able to make predictions based on the movement of their target and ensure they respond properly to the movement. However, when the athlete receives a concussion and begins to have trouble predicting movement and attending to objects it can become risky and potentially put them in immediate harm. Not only will these factors give a negative impact on their sport performance, but it can lead them to further injury without proper treatment.

Concussion groups display a significantly larger presence of saccadic intrusions during the execution of smooth pursuit several months after the last injury. The excessive presence of saccadic movements during smooth pursuit can potentially shorten fixation times and interfere with recognition and interpretation because the erratic eye movements cause gaze to stray from the intended targets too often (Dana-Dos-Santos et al., 2018). This causes an interference with an athlete's ability to judge the apparent speed of an object during play and increasing the chance of new injury. These variables would have a great influence on the performance of athletes who receive a sport-related concussion. Sports require athletes to have accurate fixation and tracking to be able to perform tasks properly and to the best of their ability. Concussed individuals also exhibit a higher initial saccade error which necessitates a larger and longer corrective saccade that results in a diminished capacity to selectively attend to objects in the visual field (DiCesare et al., 2017). This variable would be a large factor in sports that involve moving objects during a busy setting in high-contact sports. If an athlete is unable to focus on different variables that may include other players along with a ball, then they could be put into risky situations without their acknowledgment. Subjects with mild traumatic brain injury (mTBI) have statistically larger position errors, smaller saccadic amplitudes, smaller predicted peak velocities, smaller peak accelerations, longer durations and are less likely to follow a target's movement accurately (Cifu et al., 2015).

Concerning the actual movement of the eye during eye-tracking, saccadic and smooth pursuit movement can be tested to distinguish differences when tested between concussed and non-concussed athletes. Wetzel et al. (2018) found no significant differences in saccadic and smooth pursuit eye movements in their subjects, however, their results suggest there is a vulnerability of smooth pursuit and saccadic symptoms in mTBI subjects. When these eye movement variables become less accurate or slower, then their sports performance and reaction time will suffer. Research has found that CNS impairments can last long after the last concussion (Dana-Dos-Santos et al., 2018). This helps indicate that there is a need to distinguish and monitor a recovery time for athletes who receive a concussion. A lack of recovery for these individuals could be detrimental to their ability to properly perform a sport and could lead to further injury. Due to the deficits cause by oculomotor impairments, it is likely that this factor contributes to the likelihood of lower extremity risk.

Reaction Time

Research has shown that reaction time tends to increase after receiving a sport-related concussion and remain an issue for athletes longer than originally thought. It has been observed that there was a significant decline of 8.4% slower reaction time performance following sport-related concussion in a group of twenty-eight concussed athletes (Eckner, Kutcher, Broglio & Richardson, 2014). Higher complexity actions are more relatable to sports and will give more useful results that are relative to how an athlete will be affected in sport due to an increase in reaction time. These type of complex actions and situations occur more often in sport than more simplistic actions and situations. Tests with higher cognitive processing requirements and double limb action are more sensitive in detecting differences from head trauma than simple reaction time tests (Vartiainen et al., 2016). Average delays of 44.97 ms and 43.53 ms were found in the mTBI group when compared to healthy controls for both visual (M = 250.03 ms) and auditory reaction times (M = 211.00 ms) (Dana-Dos-Santos et al., 2018). Along with higher complexity movements, sports require a long duration of activity and cognitive load. Reaction time could increase further when activity and cognitive load increases. Reaction time in the concussion group was seen to increase between cognitive processing activities and measurements while it decreased in the control group (Vartiainen et al., 2016). This indicates that reaction time post-concussion can increase when the amount of activity and cognitive load requirements increase. This would be an issue for athletes since most competitions last long durations of time and require multiple cognitive functions at once with little time to take breaks and return to baseline and would likely cause reaction time to continuously increase until the competition is over.

Overall, Vartiainen et al (2016) found that concussed subjects show a trend of slowing processing speed and motor control that later resolves with recovery from the trauma. However, the recovery time has not been consistent throughout the literature and follow-up testing is not done frequently enough with concussed athletes for us to be able to make a generalized recovery length. During follow-ups post-concussion, a decrease in reaction time performance is still seen in the concussion group while there is an improvement of reaction time performance in the control group compared to both group baseline testing (Vartiainen et al., 2016). It is usually found that reaction time begins to return to baseline within a short period preceding a sport-related concussion, but little research is done to distinguish how long it takes athletes to completely recover to baseline results. At 48 to 72 hours postinjury concussed subjects had a twenty-six millisecond slower reaction time and then decreased to eighteen milliseconds slower on day seven and nine milliseconds on day ten (Del Rossi, 2017). Even though reaction time tends to decrease as time goes on athletes with concussions will still exhibit greater reaction time and do not return to baseline until day fourteen (Del Rossi, 2017). This conflicts with McGowan et al (2019) who found variability in reaction time at one month following return-to-play. It is important to recognize that there are conflicting conclusions when it comes to recovery time for athletes. Out of 26 athletes, 13 had deficits in reaction time lasting 26-30 days the other 13 had deficits lasting 43-59 days (Lempke, Howell, Eckner & Lynall, 2020). If an athlete has not fully returned to baseline even after being cleared to play it can increase their risk of further injury. Most athletes are given clearance to return to sport after a short period and time without long-lasting effects being taken into consideration. Many collegiate athletes show recovery in deficits within 28 days, but it has been found that reaction time deficits extend beyond clinical recovery (Lempke et al., 2020). Information on concussions tends to be generalized but based on the literature it is viable that we individualize recovery of sport-related concussions. Each athlete will report separate symptoms short-term as well as long-term which means there cannot be one direction that is followed for a rehabilitation process since it will not focus on symptoms or deficits for each individual. This may be the reason athletes tend to return-to-play prematurely following a concussive injury due to being cleared from the general process that is currently followed.

Psychological Deficits

The presence of a concussive injury has shown to leave immediate and long-lasting psychological effects on an athlete. Returning to competition may be a source of excitement for an injured athlete, but it may also evoke feelings of fear and anxiety regarding the uncertainties of their injury and the ability to perform at pre-injury levels (Podlog & Eklund, 2007). Many athletes get clearance to play a few weeks after sustaining a concussion, however, this clearance is based on physical aspects of the athlete improving rather than mental aspects. Out of one hundred and seventy- four participants, 11.5% of athletes who met criteria for a sport-related concussion experienced a postinjury psychiatric outcome (Ellis et al., 2015). Depression has shown to be one of the most common psychological outcomes in athletes after obtaining a concussion. Like most deficits caused by concussions, an increase in concussion frequency has a detrimental effect on the occurrence of depression. There has been an association between recurrent concussion and diagnosis of lifetime depression which could suggest that the prevalence of depression increases as concussion history increases (Guskiewicz et al., 2007). Athletes who have retired or have ended their career due to concussion are important to investigate to test the correlation between concussion and depression. These athletes can show us the severity of their depression years after their participation in sport and years after their last reported concussion. Retired NFL players who reported to have sustained three or more concussions were three times more likely to be diagnosed with depression and those who reported one or two previous concussions were 1.5 times more likely to meet diagnostic criteria for depression (Guskiewicz et al., 2007). Even players who received a lower number of concussions had lasting effects of depression from their injury. This is important to note because athletes with fewer concussions often do not get as much attention or guidance on their injury compared to an athlete who has had repeated concussions and deficits resulting from the injury. Overall, results from previous research clearly indicate that concussion frequency plays an important role in depression rates and depression severity as well as having an impact on the presence of depression as a long-term effect post-concussion (Nippert & Smith, 2008).

Depression rates and severity can be influenced by other factors brought on by injury as well. For many athletes, the clearance to return to their sport is the most important factor post-injury due to the personal identification they place on their sport. An overarching theme when investigating an athlete's perception and experience of injury involves the athlete viewing their injury as a threat to their identity as an athlete (Rosen et al., 2018). Many athletes view their sport as a priority in their life and make a variety of personal and health related risks to ensure they can continue to play. Some athletes decide to continue to train and compete through their injuries to avoid a loss of identity with their sport and to avoid the mental effect that would come from not participating. Results have shown that collegiate athletes who identified highly with their sport and their role in their sport were more likely to respond to an injury with symptoms of depression (Nippert & Smith, 2008). The athlete may still have depressive symptoms after returning to play with their injury especially if they are aware that they are not as strong and efficient of a player as they were pre-injury. Identifying athletes with such attributes may suggest which athletes that might respond more negatively to injury in terms of self-identity which also might be an important factor to address during the rehabilitation stage following concussion in order to place importance on the onset of depressive symptoms (Rosen et al., 2018).

The physical components of injury are often the focus during treatment and rehabilitation. Psychological factors involved in a sport related injury are minimized and end up escaping detection (Nippert & Smith, 2008). However, these psychological factors can impact athletes long-term without proper acknowledgement and attention. In order to tests effects that concussion may have on psychological state, patients complete the Post-Concussion Symptom Scale (PCSS), an inventory that consists of 22 symptoms, classified as physical, cognitive, sleep, or emotional (Ellis et al., 2015). This inventory will identify what symptoms can be relative to concussion and how their injury effects their mental well-being rather than focusing on physical deficits that have occurred. This inventory can be used throughout treatment and during follow up treatment of a concussion to indicate any changes in symptoms. Without recognition, psychological stressors may negatively impact rehabilitation and sport performance upon return to the sport (Nippert & Smith, 2008). When sport performance is negatively impacted, it can continue to lead an athlete to further injury.

Self-efficacy

Self-efficacy is the belief in oneself to execute skills in a confident manner that leads to successfully completing a task. Self-efficacy can be developed though four main sources of influence that affect a person's belief to succeed in a situation (Bandura, 1977). The first source of self-efficacy influence is mastery experience. This source is said to be the most influential source because it provides authentic evidence of one's ability or performance during a situation (Bandura, 1977). The second source of influence is vicarious experiences. This involves a person observing others successfully completing a task that can create a belief that they possess the capabilities to master the activity as well (Bandura, 1977). The third source of influence is imaginal experiences. This source involves a person visualizing themselves behaving effectively or successfully during a situation (Bandura, 1977). The final source of self-efficacy influence is verbal persuasion. This is typically done through suggestion that a person has the skills and capabilities to succeed (Bandura, 1977). A person's beliefs about their own abilities does has an impact on executing those abilities in situations. If they are not confident in their abilities to perform then it can have a negative effect on performance and lead to inappropriate execution of skills that are necessary for success during a task.

Some researchers have also begun to investigate the psychological aspects of concussion and its relation to cognitive and motor functions. More specifically this type of research investigates the relationship between self-efficacy and return-to-play post-injury. It has been found that confidence, as a form of self-efficacy, is connected to performance and that an injury could consequently affect an athlete's perspective of each of these aspects (Skinner, 2013). If injured athletes view themselves as having lower confidence when returning to their sport, their performance will most likely be negatively affected as well. The way that an athlete views themselves as an athlete pre and post injury could be an indication of the effects of a concussion and how they continue to play a role when an athlete is cleared for return-to-play. There have been few studies that have investigated the comparison of *self-appraisal* (how a person sees oneself) and *reflective appraisal* (how the person thinks that others see him or her) (English, St Pierre, Delahay & Parente, 2016). These types of comparisons would help relay how large of a factor self-efficacy plays on sport and distinguish why an injury could have such a detrimental effect on an athlete. The purpose of investigating this relationship is to attempt to find if self-efficacy and return-to-play after concussive injury increase the risk of lower extremity injury. If players perceive themselves to be less competent in their sport, it can potentially result in their decision to make riskier decisions or make the wrong decisions while in play which would also put them at risk of receiving a lower extremity injury. However, there has been little research on return-to-play and self-efficacy specific to concussive injuries as opposed to other forms of sports injuries.

After athletes receive an injury, they can be affected physically and psychologically which will likely decrease their self-efficacy or competence in their sport. Using a bi-weekly questionnaire, researchers gathered information about athlete's perception during and after their injury (Rosen et al., 2018). Athletes often have negative feelings towards their injury during and after the rehabilitation process. It has been seen that many athletes continue not to have full confidence in their athletic performance proceeding rehabilitation and after clearance for return-to-play. This reasoning has caused many athletes to decide not to return to play after their injury. Arden et al (2014) found the main reasons for not returning were not trusting the knee, fear of new injury, and poor knee function. The fear of reinjury is common among many athletes when returning to play which is relative to a lower confidence level for their sport and for their previous injury (Patel et al., 2019). Reinjury fears may manifest themselves in several ways, including being hesitant and holding back during competitive play (Padlog & Eklund, 2007). These reasons relate to self-efficacy due to the added fear the athletes now have toward their sport. If the athletes who responded this way were to return to sport their confidence would be low, and they may not make the correct in-play decisions out of fear of reinjury or feeling as though they are not fully recovered. However, knowing there is a difference in self-efficacy and return-to-play after a lower extremity injury could indicate that there will be differences found in athletes who received a concussion during sport as well. It would be beneficial to recruit athletes who return-to-play after a concussive injury so proper data can be collected based on their perceived changes in ability and performance.

To test the self-efficacy of athletes concerning sport there are different forms of inventory tests and questionnaires have been used. Executive functioning is measured by the Behavior Rating Inventory of Executive Functioning (BRIEF) (English et al., 2016). This instrument consists of nine subscales of executive functioning: task-monitoring, working memory, inhibition, organization of materials, initiation, shifting, emotional control, planning, and organization, and self-monitoring (English et al., 2016). The use of this form of inventory can help distinguish the self-efficacy of athletes post-concussive injury by evaluating how the athlete feels about returning to their sport and if they feel as though they are fully recovered enough to return to their sport as the same player they were preinjury. It has been found that concussion groups appraisal relationships suggest that these individuals are less influenced by others' perceptions and their self-appraisals are inaccurate (English et al., 2016). Another inventory that assesses self-efficacy and return-to-play is the Sport Confidence Inventory (SCI). This inventory indicates how confident the athlete is in their ability to properly perform in their sport (Vealey &

Knight, 2002). The survey has generally been used to evaluate sport confidence not in relation to injury and return-to-play. However, this questionnaire could be used on athletes to rate how or if their confidence in their abilities have changed post injury and if they feel as though they are at the same level of play as they were pre-injury. This measure could indicate an athlete's uncertainty when they return to their sport and show the mechanisms behind an increased risk of injury after concussion. When the athlete is aware of themselves having lower confidence, they may begin to make poor decisions during play that puts them at risk of injury. Uncertainty can become a risk factor for athletes during play due to the pace of the game and the constant changing environment they are a part of.

Brain Activity

To test cognitive functions in recovering concussion patients in athletics, many research studies have used devices such as fMRI, EEG and MRI, and focused on certain brain functions to assess brain activity. Mainly, tests have shown that there are deficits in retention, attention/concentration, and reaction time. However, recent studies have begun to test the relationship between lower extremity injuries and concussions based on results of brain function differences between concussed and non-concussed athletes. Studies have suggested that specific deficits may put concussed athletes at an increased risk of injury, however there is little data regarding the actual risk of injury associated with concussion (Brooks et al., 2016). An EEG would be able to assess cognitive control processes and brain activation is concussed and non-concussed athletes. Electroencephalogram detects electrical activity in the brain using electrodes that are placed on the scalp. EEG activity was recorded on 37 male athletes while they took a post-concussion symptom scale, 30-min standardized concussion interview, and serial reaction time task (Beaulieu et al., 2019). The researchers found that psychomotor speed slowed down in those who were concussed for around four months post-injury (Beaulieu et al., 2019). This means that decision-making and initiation of actions is delayed as a result of injury which indicates changes to the frontal lobe region of the brain. If this decrease in response occurs in concussed athletes, then the likelihood of these deficits affecting risk of injury would most likely increase. This could either be due to a delay in response creating situations for an athlete to put themselves in a high injury risk position or could cause the athlete to make riskier decisions that are not based on previous learning of the sport.

Certain cognitive tasks alongside fMRI can help us distinguish what changes are occurring in brain activation in concussed athletes compared to non-concussed athletes. For instance, these differences in brain activation can be seen more accurately when using oculomotor tasks alongside fMRI. It is apparent that impaired oculomotor performance can change neural underpinnings that causes widespread increased activation of multiple brain areas regardless of oculomotor task difficulty (Johnson et al., 2015). These differences in brain activation can potentially cause delays and deficits which can decrease overall efficiency of the brain of concussed athletes. Event-related brain potentials can be measured using EEG and can indicate certain sensory, cognitive, and motor event responses and changes that are occurring in the brain to distinguish overall brain functioning. It has been found that athletes with a history of concussion have shown to exhibit a greater P1 amplitude and latency which indicates an overall inefficiency in early perceptual aspects of working memory (Hudac et al., 2015). This can cause athletes to either have delayed visual processing of stimuli or deficits in attention which can be unfavorable during athletic performance. Athletes rely on quick response to stimuli and awareness of their environment during play in order to have a successful performance and execute athletic skills properly. Since the parietal region of the brain plays a role in functions such as navigation and understanding spatial orientation, any differences to this region should be investigated in order to compare changes that occur in athletes after a concussive injury (Hudac et al., 2017). These compensatory mechanisms can be seen post return-to-play and can affect reaction time and attention during athletic performance. With these lingering deficits it is beneficial to investigate the reasoning and occurrence of the changes in brain activation in concussed athletes and distinguish how it can negatively affect athletes who are returning to play post-concussion.

Athletes who receive concussions generally have changes to their brain function and activation that can go undetected during certain neuroimaging measures and cognitive testing. However, the use of functional magnetic resonance imaging (fMRI) analysis has revealed significant differences in brain activation patterns in concussed individuals when compared to non-concussed individuals. fMRI is used measure brain activity by detecting changes in blood flow throughout the brain (Keightley et al., 2014). It has been found that concussed athletes demonstrate increased and larger areas of activation when compared to non-concussed athletes (Johnson, Hallett & Slobounov, 2015). This could be due to the concussed athletes needing other areas of the brain to work harder in order to compensate for the damage done to areas of the brain used for specific tasks. It is possible that athletes with a history of concussion recruit additional attentional resources during tasks that tax working memory in order to compensate for deficits in the working memory system, even after acute symptoms of concussion have resolved (Hammeke et al., 2013). The increased brain activity response found in concussed athletes is an important factor to investigate when deciding on severity of the injury and any lasting effects that have come about due to the injury that may affect day-to-day activities. Athletes with a history of concussion have demonstrated different electrophysiological and brain source responses during working memory tasks (Hudac et al., 2017). Some fMRI investigations report decreased neural activity in concussion groups compared to controls in regions related to working memory including the dorsolateral and medial prefrontal cortex (Van der Horn et al., 2017) and the left superior parietal lobule (Keightley et al., 2014). Working memory tasks are important in athletic performance because they can be used in overall decision-making during play and can be used for reasoning as well.

Event-related spectral perturbations (ERSP) can indicate the total neural activity during cognitive testing and distinguishes brain dynamics (Rossi et al., 2014). Theta, alpha and beta EEG frequency bands have been used in different tasks and conditions to distinguish changes in frequency (Rossi et al., 2014). These frequencies have been used to test different cognitive processes during certain tasks. It has been found that decreases in alpha band activity have been related to attentive processing of stimuli and increases in the beta band to maintenance of the current brain state (Engel & Fries, 2010). Other studies have found that concussed participants exhibit an increase in theta frequency which may affect attentiveness during task as well (Munia, T.T.K., Haidner, A., & Fazel-Rezai, R., 2017). This information indicates that ERSP has a role in information processing and communication with the brain during cognitive tasks. These frequencies would be important to test under cognitive tasks with individuals who have a concussion and compare their results to individuals without a concussion in order to find between-group differences or similarities.

The way an athlete responds to and reacts to incoming stimulus is an important area of brain functioning to investigate and to distinguish potential changes and deficits. EEG can be used to measure this using specific event-related-potentials like P3, which is an ERP that is a component of decision-making but is also linked to a person’s confidence and reaction to responding to a stimulus (Keightley et al., 2014). This ERP is important since it is assessing a person's response to a stimulus, which is a key factor in athletics since athletes must constantly react to stimuli during participation. It has been observed that there is increased activation in brain regions associated with the manipulation of information in working memory for concussed groups during the P3 window when measuring these subjects with an EEG which may indicate that an overload of working memory could increase electrophysiological response and increased activation in task-relevant brain regions (Hudac et al., 2017). In other words, this suggests that there is a reduction in the efficiency of the working memory system in concussed individuals and that these individuals display increased activation within working memory regions to achieve accuracy. This indicates that there are some long-term changes in the allocation of neural resources needed to update working memory following concussion. These findings emphasize the ongoing vulnerability and neural changes associated with a concussive event, even long after somatic symptoms have resolved, and athletes have been cleared to return to athletic activities and academics (Hudac et al., 2017).

The most important finding from previous research is that these activation differences last longer than previously thought and could last after an athlete is cleared for return-to-play. fMRI analysis has shown that at 30 days postinjury, concussed athletes brain activity more closely mirrors that of a non-concussed group than they did at 7 days following their initial injury (Johnson, Hallett & Slobounov, 2015). These differences in brain activation over long periods of time can have detrimental effects on an athlete's ability to perform properly during their sport. Since competitive athletics involve high cognitive loads, impairments in the executive allocation of attention may contribute to inappropriate motor performance and influence the risk of lower extremity injury (Fino et al., 2019). This suggests that impaired cognitive efficiency after concussion, particularly during dual cognitive and motor tasks, may be a factor in the risk of lower extremity injury (Fino et al., 2019). Due to this, it would be especially important to focus on the frontal lobe region of the brain for concussed individuals in order to compare differences in processing and responses during certain tasks that athletes would encounter during play. Athletes are rarely in situations during play that involve simple cognitive tasks as they usually are involved in multiple tasks at once which means they would be greatly impacted by any cognitive impairments. These impairments and differences in brain activation are important factors for the reduction of potential injury as well as ensuring an athlete is fully recovered and ready for return-to-play at the same level they were pre-injury.

Lower Extremity Injury Risk

Deficits to an athlete caused by a concussion can have long-term effects and add risk when the athlete is cleared for return-to-play. One of the main concerns when athletes are cleared is that their deficits will continue to put them in situations that can result in further injury. Intercollegiate athletes are found to have a 1.6 to 2.9 times elevated risk of lower extremity injury if they have suffered a concussion during any point of their athletic career (Gilbert, Burdette, Joyner, Llewellyn & Buckley, 2016). There is a significant difference between this type of injury occurrence in concussed athletes when compared to non-concussed athletes as well. The incidence of lower extremity injury is 8% higher among concussed athletes compared with matched controls (Brooks et al., 2016). However, recent studies have found that the percent of risk difference in concussed and non-concussed athletes may be even greater. According to Fino et al (2019), concussed groups have a 67% greater instantaneous risk of lower extremity injury compared to those who have not suffered from a concussion. These findings do not have a clear reason as to why this is occurring at such significant levels, but they allow us to make the realization that long-term concussive deficits have a huge impact on further injury of lower extremities.

Most importantly, the length of time post-concussion has not been seen to change the level of risk for a lower extremity injury. An increased risk of lower extremity injury within a year of a sport-related concussion has been seen in athletes even after clearance for return-to-play (Fino et al., 2019). This may indicate that the athletes who receive clearance are still suffering from certain deficits that continue to put them at risk for further injury during sport participation. Brooks et al (2016) tested concussed collegiate athletes during a ninety-day period after they were cleared to return-to-play and found they were 2.48 times more likely to sustain a lower extremity injury compared to those who had not received a concussion. Even though contact sports already have an increased risk for other forms of injury, it has still been found that the risk increases if an athlete suffers from a sport-related concussion. The risk of these types of injuries has also been found to increase based on the frequency of reported concussion. Athletes who report three or more concussions have significantly higher associations for lower extremity injury categories (Pietrosimone, Golightly, Mihalik & Guskiewicz 2015). This could indicate that the severity of deficits caused by concussions could have a great impact on the occurrence of lower extremity injury and would make the athlete more susceptible to further injury.

It has been shown that poor neurocognitive performance, either at baseline or in the aftermath of a concussion, is associated with elevated risk of lower extremity injury (Herman et al., 2015). However, it is still unclear specifically why the incidence of lower extremity injury increases and what factors cause this to occur in athletes. The increased injury risk following sport-related concussion suggests that routine care does not fully capture persistent neuromuscular and neurocognitive deficits associated with lower extremity injury. In order to understand what is causing this trend, further research will have to be conducted based on cognitive and psychological deficits to see how they affect lower extremity injury.

Summary

The nature of athletics demand participants to initiate and maintain appropriate performance of dynamic activities in a rapidly changing environment. The success of these actions is contingent on voluntary and involuntary motor commands like reaction time and oculomotor performance (Herman et al., 2015). Since these motor commands can be affected by a sport related concussion, it is likely that they contribute to increasing the risk of lower extremity injury. These deficits likely effect neuromuscular control, motor learning, and other aspects critical for the performance and safety of the athlete (Herman et al., 2015). The research on sport-related concussions is mainly based on short-term effects and not long-term effects. It is important to recognize that there has been conflicting literature based on recovery especially when it comes down to specific types of cognitive or psychological deficits. Reaction time, oculomotor performance, and self-efficacy are factors that remain effected in athletes up to months after they are cleared to play. Therefore, the purpose of this study was is to show these physical and psychological effects of concussion cause deficits in those inflicted that result in a higher risk of lower extremity injury

Chapter III. Methods

Introduction

This study aimed to acquire quantitative measurements of sport-related concussion deficits in athletes at a university. Separate questionnaires and measures were used to receive data from the participants based on their oculomotor performance, self-efficacy, and reaction time. Reaction time and oculomotor performance were measured through a visual task while self-efficacy was measured through a questionnaire. This study occurred within a two-year period of reported occurrence of a sport-related concussion.

Participant Characteristics

<u>Aim 1</u>

The Concussion and Return-to-Play Confidence Survey included nine participants who are currently involved in a collegiate, club, or recreational sports and have received at least one sport related concussion within a two-year period. Of the nine participants who completed the survey there were five males and four females. Their ages ranged from 18 to 23 with a mean age of 20.56 ± 1.74 years.

<u>Aim 2</u>

The GO/NO-GO task and concussion and lower extremity injury surveys included twenty-five participants. Five participants were recruited who have reported a sport related concussion who are currently involved in a collegiate, club, or recreational sports. The type of sport these participants were involved in included basketball (20%), volleyball (20%), rugby (20%), soccer (20%), and marching band (20 %). Twenty of the participants were part of the control group. The control group consisted of individuals who have not received a concussion. 30% of the control group indicated that they are currently involved in a collegiate, club, or recreational sports. These sports included rugby (50%), dance (16.67%), frisbee (16.67%), and softball (16.67%). The age range of the twenty-five participants who participated in the surveys and task was 18 to 30 with a mean age of 21.24 ± 2.803 years. The race of the participants consisted of mainly Caucasians (68%), Afro-American (20%) and Asian/pacific (12%). Testing was done within a two-year time frame from an initial injury.

Inclusion Criteria for Concussed Group

1. Athletes at the collegiate, club, or recreation level who have received at least one concussion during their sport season
    a. Athletes with concussion who have and have not received a lower extremity injury
2. Any severity and frequency of a concussion is allowed if the athlete can be cleared to return to play
3. Currently playing the sport they received their injury in

Exclusion Criteria for Concussed Group

1. Athletes who are not cleared to return-to-play will be excluded from the study since we are looking at deficits of those who are continuing in their sport
2. Participants who have received a concussion but are not part of athletic activities will also be excluded from the study

Instruments

1. Concussion and Return-to-Play Confidence Survey - The questionnaire was modified from the Sport-Confidence Inventory and ACL-Return-to-Sport after Injury Scale Questionnaire (St. Luke's Sports Medicine) to relate the items to concussive injuries (Vealey & Knight, 2002). It included items based on confidence and fear that the participant may encounter post-injury when they are cleared to return to sport. For example, one item asked participants to rank their confidence in returning to play their sport without concern of their concussion on a Likert scale 1 (not confident at all) through 7 (totally confident I can do it). The questionnaire also included background information of the athletes regarding when they received their most recent concussion and the length of time they were unable to fully participate in practice and games.
2. Concussion Survey- The questionnaire included information based on participant concussion history as well as the date(s) they received their concussion. Those who had received a concussion were able to self-report their injuries and indicated the frequency of the injuries they experienced. Any injury reports that exceeded the two-year period were not included in statistical analysis.
3. Lower Extremity Survey- The questionnaires included information based on participant lower extremity injury history as well as the date(s) they received their lower extremity injury. Those who had received a lower extremity injury were able to self-report their injuries and indicated the frequency of the injuries they experienced. Any injury reports that exceeded the two-year period were not included in statistical analysis.
4. Tobii HTC VIVE Pro Eye virtual reality eye tracking enabled headset
5. G-Tec (500 Hz) 32 channel EEG cap

Measurement Protocol

All procedures were approved through the University Internal Review Board (IRB) and all participants were provided with written informed consent. Initial testing began within two years post an athlete's report of a sport-related concussion. This is because this study is focused on the long-term effects of concussion and gives a waiting period for the occurrence of a lower extremity injury.

Aim 1

Self-Efficacy

Before completing the GO/NO-GO task all participants were asked to complete the Concussion and Return-to-Play Confidence Survey to measure their self-efficacy relative to their sport (See Appendix A). Some of the participants were verbally recruited when they came in to complete the tests in Aim 2 if they met the criteria for the questionnaire. The rest of the participants were recruited through email that was sent to club and intramural teams and departments at East Carolina University.

Aim 2

Concussion and Lower Extremity

The concussion and lower extremity injury questionnaires were used to gather background information from all participants in the concussion and control group (See Appendices C and D). This aided in separating this data from participants into three groups of those with no concussion with presence of lower extremity injury, concussion with the presence of at least one lower extremity injury, and concussion with no lower extremity injury for statistical analysis.

Participants completed the questionnaires prior to completing the GO/NO-GO task. Participants were recruited through email including a study flyer that was sent to club and intramural teams and departments at East Carolina University.

Oculomotor Performance

The final test involved a GO/NO-GO task that was presented in a Tobii HTC VIVE Pro Eye virtual reality eye tracking enabled headset. The participants traveled down a virtual pathway while visually tracking targets moving through space. While the participants continued to move forward, GO targets would become present in which the participant needed to press on a trigger as soon as possible after viewing. The trigger would make a mark when pressed during the data collection. Periodically a NO-GO target appeared, and the participant would have to decide to not press on the trigger when they viewed this target. Each participant complete three thirty second trials of the task. The dependent variables tested included reaction time and saccadic eye movements.

Brain Activity

During the GO/NO-GO test, the participants were asked to wear a G-Tec (500 Hz) 32 channel EEG cap to measure reaction time while they perform the necessary tasks. During the task, a marker indicating the occurrence of a target in relation to when the subject responded to the target. Brain activity was assessed during the full time (30 seconds) of each of the three trials to indicate when and how the participants were reacting. This aided in collecting any differences in brain activity between the concussion and control group.

Data Processing

Aim 1

Self-efficacy was recorded using the scores and answers each athlete obtained after taking the Concussion and Return-to-Play Confidence Survey. The questionnaire also helped indicate any frequencies of concussion within a two-year period to distinguish any effect on repeated injury to self-efficacy.

Aim 2

Oculomotor performance and reaction time was recorded using Tobii HTC VIVE Pro Eye virtual reality eye tracking enabled headset. This headset recorded eye movement during the GO/NO-GO task based on reaction time, attention, and focus. Saccadic eye movements were determined by their velocity level when attending to stimuli during the GO-NO/GO task to determine any differences in these eye movements between the groups (Cifu et al., 2015). Custom Python scripts were used to process target cue time, saccadic eye movement time, and saccade reaction time in relation to trial number and participant number from the Tobii HTC VIVE Pro Eye virtual reality eye tracking enabled headset. The data was then exported into an excel workbook to prepare it for statistical analysis. A G-Tec 500 Hz EEG was used to record brain activity in the concussion and control group. The data found from the participants wearing the G-Tec EEG cap during the GO/NO-GO task was first preprocessed for analysis using MATLAB Version 2021a. High-pass and low-pass filters were applied to the data to create a band-pass filter of 1-35 Hz. The data was then analyzed using EEGLAB Version 2020.0 toolbox to create ERSP head plots and MATLAB Version 2021a to create ERSP graphs. ERSP was measured during the GO/NO-GO task in order to test theta (4-8 HZ), alpha (8-12 Hz), and beta (13-30 Hz) fluctuations in spectral power for these frequencies (Rossi et al., 2014). This data was then analyzed using brain topographic maps The ERSP distributions for ten representative electrode locations (Fp1, Fp2, F3, F4, F7, F8, Pz, P3, Po3, Po4) were derived as a function of time (0-500 ms from stimulus onset) and frequency (1-30 Hz) using a Morlet Wavelet code on MATLAB Version 2021a. This will be used to distinguish any increase or decrease in frequency bands at these channel locations to find differences in brain activity between the control group and concussion group. This data can also be used to find differences in the concussion group based on frequency of concussion.

Statistical Analysis

SPSS Version 27 was used to conduct all statistical analyses. Frequencies, mean, mode and standard deviation, were calculated for age, gender, race, current participation in sport, occurrence of concussive injury, and occurrence of lower extremity injury. Mean, frequency, and standard deviation of different measures from the return-to-play questionnaire and the concussion and lower extremity injury questionnaires. Pearson's correlation analyses were used to study the relationship between the report of a concussion and the presence of lower extremity injury as well as the relationship between participation in sport and report of concussion or lower extremity injury. Saccadic eye-movement data from the Tobii HTC VIVE Pro Eye virtual reality eye tracking enabled headset was imported into excel to find saccadic eye movement reaction time by subtracting cue time and saccade time for each trial completed by the participants. The saccadic eye movement reaction time was then run through descriptive statistics to indicate means and standard deviation between participants and each trial number for the participants. For data from the EEG, event-related spectral perturbation (ERSP) differences between the concussed group and the control group were completed using EEGLAB Version 2020.0. The ERSP data was then analyzed on MATLAB Version 2021a using decibel corrected analyses using $p<.05$ to indicate the statistically significant changes between the concussed group and control group in the left frontal, right frontal, and parietal regions of the brain. A baseline of 100ms was created to represent normalization in which any increases or decreases of power would be represented at time points after baseline.

Chapter IV. Results

Results

<u>Aim 1</u>

Self-Efficacy

Descriptive statistics indicated that 22.2% of athletes reported that they had received at least one concussion during sport participation (recreational, practice, game), while 77.8% reported that they received two or more concussions. In addition, 88.8% of athletes reported that they returned to play within a month of their concussion, with only one athlete reporting that they did not return during the same season they were injured. The mean scores for some of the items from question #13, "When returning to play, to what extent were you confident in your abilities to…" (see Table 1). The mean score for item "perform at your previous level of sport performance?" was 4.11 which indicates that athletes felt mid to low levels of confidence to perform at their level of sport performance when they were cleared to play after their concussive injury. The mean score for the item "play your sport without concern of your concussion?" was 3.56 and the mean score for the item "successfully make critical decisions during competition?" was 4.33.

Table 1. Means and standard deviations for Question #13 "When returning to play, to what extent were you confident in your abilities to…"

	M	*SD*
successfully manage your nervousness so that it doesn't hurt your performance?	4.33	1.581
perform at your previous level of sport performance?	4.11	1.537
play your sport without concern of your concussion?	3.56	1.810
react on time during play?	4.44	1.810

focus on your target during play?	5.56	1.944
be aware of your surroundings during play?	4.78	1.394
execute the physical skills necessary to succeed?	5.78	1.093

Note. The reported means are a product of each participant (n = 9) rated each question on a Likert scale 1 (not confident at all) to 7 (totally confident, absolutely sure I can without a doubt)

The percentage of athletes that chose certain items for "Which of the following statements best describes you when you returned to play? Circle all that apply." (question #11) found that 44.4% of athletes chose the items "I held back to prevent getting re-injured" and "I doubted I was fully recovered". (See Figure 1). Only 11.1% of athletes chose the item "I was confident about playing again", which means that 88.9% of athletes did not feel confident about returning to play after their concussive injury.

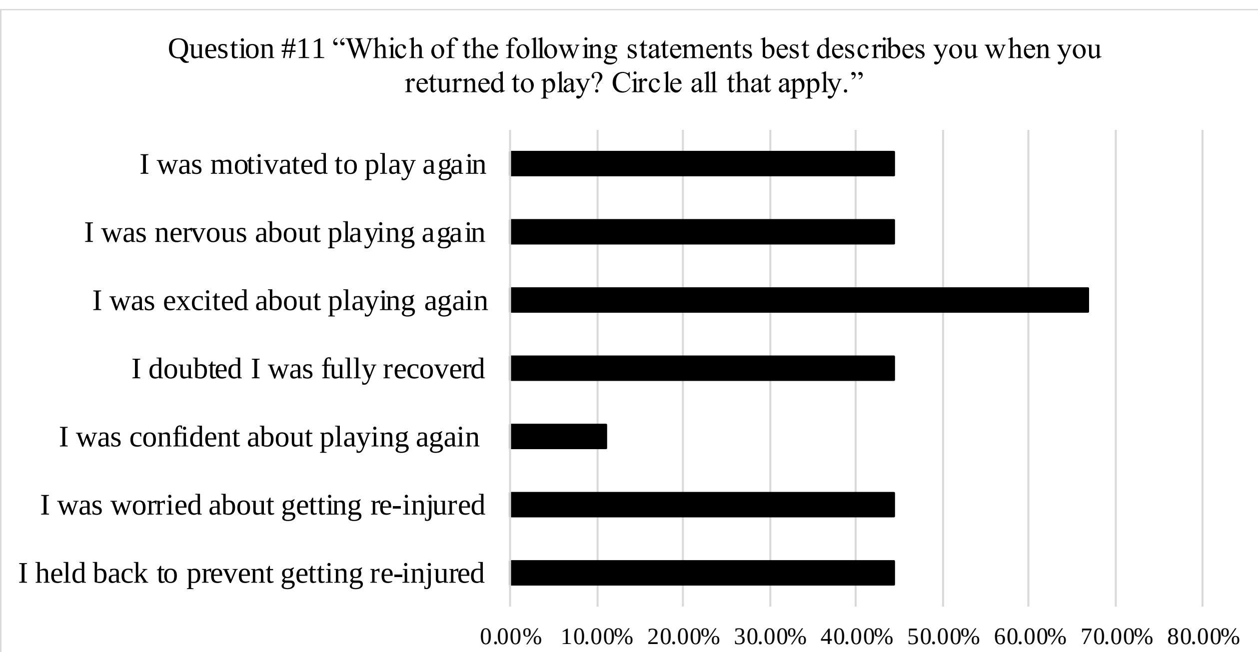

Figure 1. Frequency in percentage of items the participants (n=9) chose for Question #11 "Which of the following statements best describes you when you returned to play? Circle all that apply.".

Aim 2

Concussion and Lower Extremity

Descriptive statistics indicated that 20% of the participants received at least one concussion within the past two years, with 48% receiving at least one lower extremity injury within the past 2 years. Five (20%) participants did not meet the two-year period for concussion and were used as control participants. The highest number of reported concussions within the past two years was two and the highest number of reported lower extremity injury within the past two years was three. Out of the twenty-five participants, 44% of them indicated that they were athletes on a school team, club or intramural team, or organized recreation team. As shown in Table 2, there was a statistically significant (p<.01) correlation between sport participation and occurrence of concussion within a two-year period. However, the relationship between sport participation and occurrence of lower extremity injury within a two-year period and the relationship between report of a concussion within a two-year period and report of a lower extremity injury within a two-year period were not statistically significant.

Table 2. Correlations for sport participation, concussion within two years and lower extremity injury within two years

	Sport	Concussion	LEI
Sport	1	.564**	.116
Concussion		1	.120
LEI			1

Note. *p < .05. **p < .01. ***p < .001.

Oculomotor Performance

When the mean and standard deviation of saccadic eye movement reaction time for each participant during the GO/NO-GO task trials was computed, the results indicated that they were no statistically significant differences in saccadic eye movement reaction time during the task between the concussed group and the control group.

Brain Activity

A comparison of channel spectra was completed for the concussed group and the control group for theta, alpha and beta frequency bans for all channels (See Figure 2 and 4). These figures show that there are statistically significant differences in the frontal region and parietal region of the brain between the concussed and control group. More specifically, this indicates that there were significant (p=.05) theta differences between the two groups in the frontal and parietal region of the brain (See Figure 2). There were significant (p=.001) alpha differences between the two groups in the frontal and parietal region of the brain (See Figure 3). There were significant (p=.05) beta differences between the two groups in the frontal left region of the brain (See Figure 4).

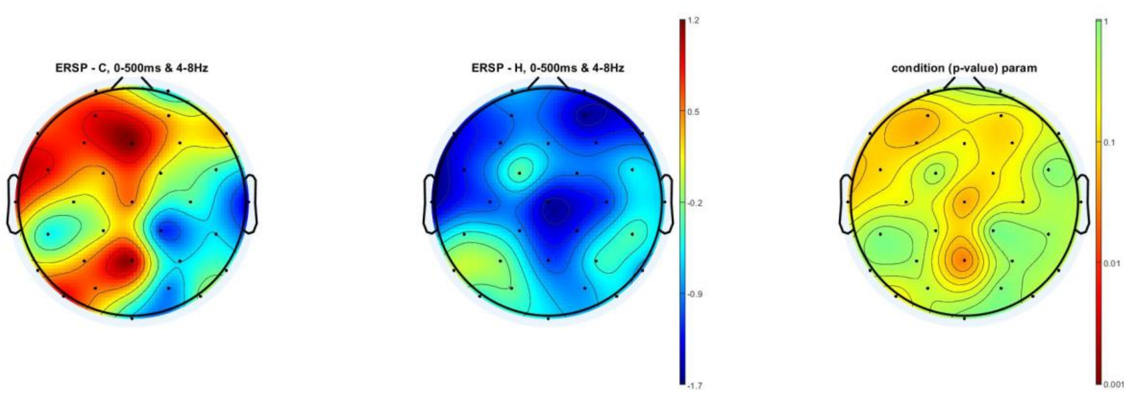

Figure 2 Theta (4-8 Hz) spectral comparison between concussion and control participants from 0-500ms after target presentation. The left topographic map shows the channel spectra mapped for the concussed group. The middle topographic map shows the channel spectra mapped for the control group. The blue indicates the lowest power while change of color towards red indicates a gradual increase in power. The right topographic map indicates the

significance of differences in power between the two groups. the light green indicates low significance while change of color toward dark red indicates a gradual increase in statistical significance. Black boxes surround areas of statistically significant differences between concussed and control groups from 0-500ms after target presentation.

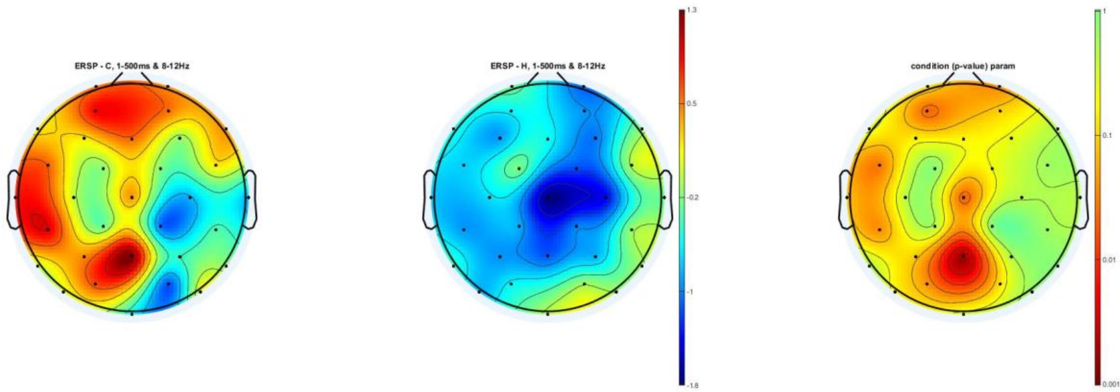

Figure 3 Alpha (8-12 Hz) spectral comparison between concussion and control participants from 0-500ms after target presentation. The left topographic map shows the channel spectra mapped for the concussed group. The middle topographic map shows the channel spectra mapped for the control group. The blue indicates the lowest power while change of color towards red indicates a gradual increase in power. The right topographic map indicates the significance of differences in power between the two groups. the light green indicates low significance while change of color toward dark red indicates a gradual increase in statistical significance.

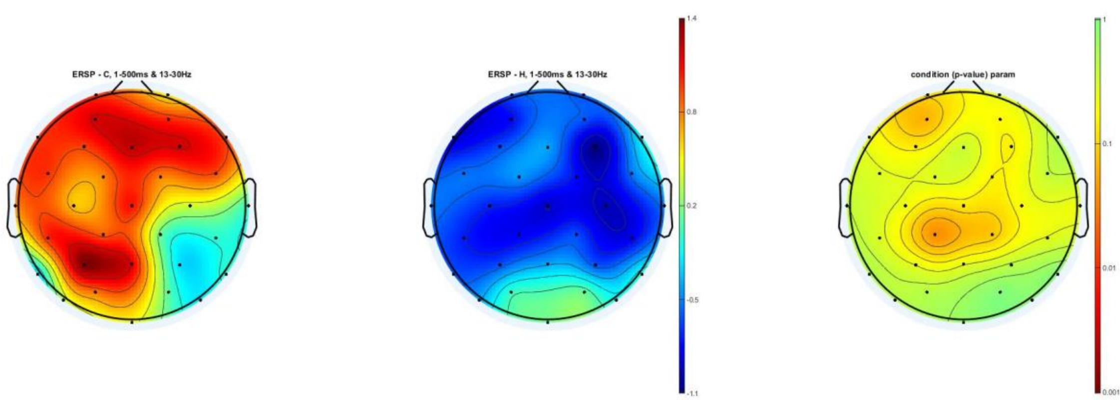

Figure 4 Beta (13-30 Hz) spectral comparison between concussion and control participants from 0-500ms after target presentation. The left topographic map shows the channel spectra mapped for the concussed group. The middle topographic map shows the channel spectra mapped for the control group. The blue indicates the lowest

power while change of color towards red indicates a gradual increase in power. The right topographic map indicates the significance of differences in power between the two groups. the light green indicates low significance while change of color toward dark red indicates a gradual increase in statistical significance.

A comparison of ERSP at a significant level of $p<.05$ was completed for the concussed group and the control group in relation to time and frequency at the left frontal brain region, right frontal brain region, and the parietal brain region (See Figure 5, 6, 7). In the left frontal area for the concussed group there is event related synchronization (ERS) occurring across each frequency, mainly in the high theta low alpha range at 150ms to 400 ms and in the beta range at 400ms to 500ms, while event related desynchronization (ERD) is occurring in the beta frequency at 200ms to 300ms (See figure 5). The control group indicates there is ERS occurring at the theta frequency during 200ms to 400ms and ERD occurring at the beta frequency during 150ms to 500ms. In the right frontal area for the concussed group there is ERS occurring at the alpha frequency from 150ms to 450ms and the theta frequency from 250ms to 400ms while ERD is occurring at the beta frequency from 150ms to 300ms (See figure 6). The control group indicates there is ERS occurring at the theta frequency from 200ms to 350ms and at the beta frequency from 150ms to 300ms while ERD occurring at the alpha and beta frequencies from 200ms to 500ms. In the parietal area for the concussed group there is ERS occurring at the theta and alpha frequencies during 150ms to 500ms and ERD occurring at the beta frequency from 100ms to 100ms to 400ms (See figure 7). The control group indicates there is ERS occurring mainly at the theta frequency from 150ms to 400ms and ERD occurring mainly in the beta frequency from 150ms to 400ms.

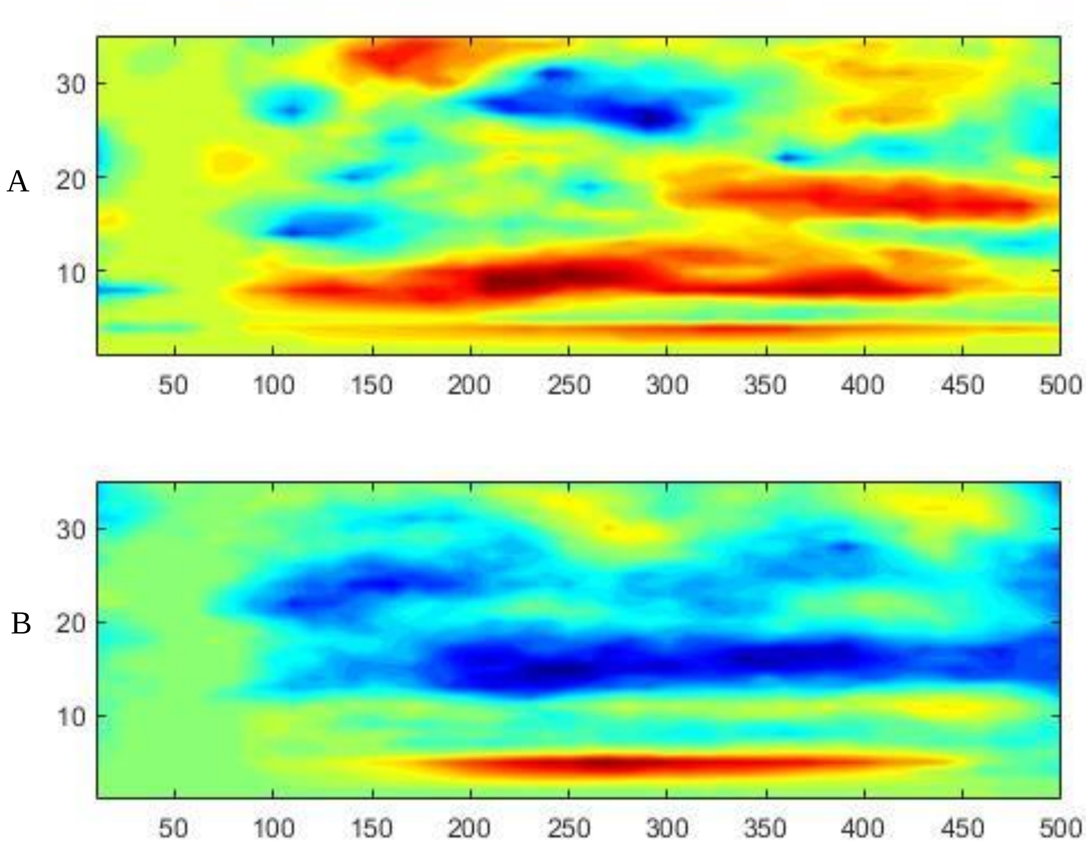

Figure 5 Left Frontal brain region spectral comparison between concussion (A) and control (B) participants. The images indicate decibel corrected mean event-related changes in spectral power at each time during the epoch at each frequency (1-35 Hz) across time (0-500ms). The blue indicates the lowest power while change of color towards red indicates a gradual increase in power. The green area represents no significant (p<.05) change from baseline.

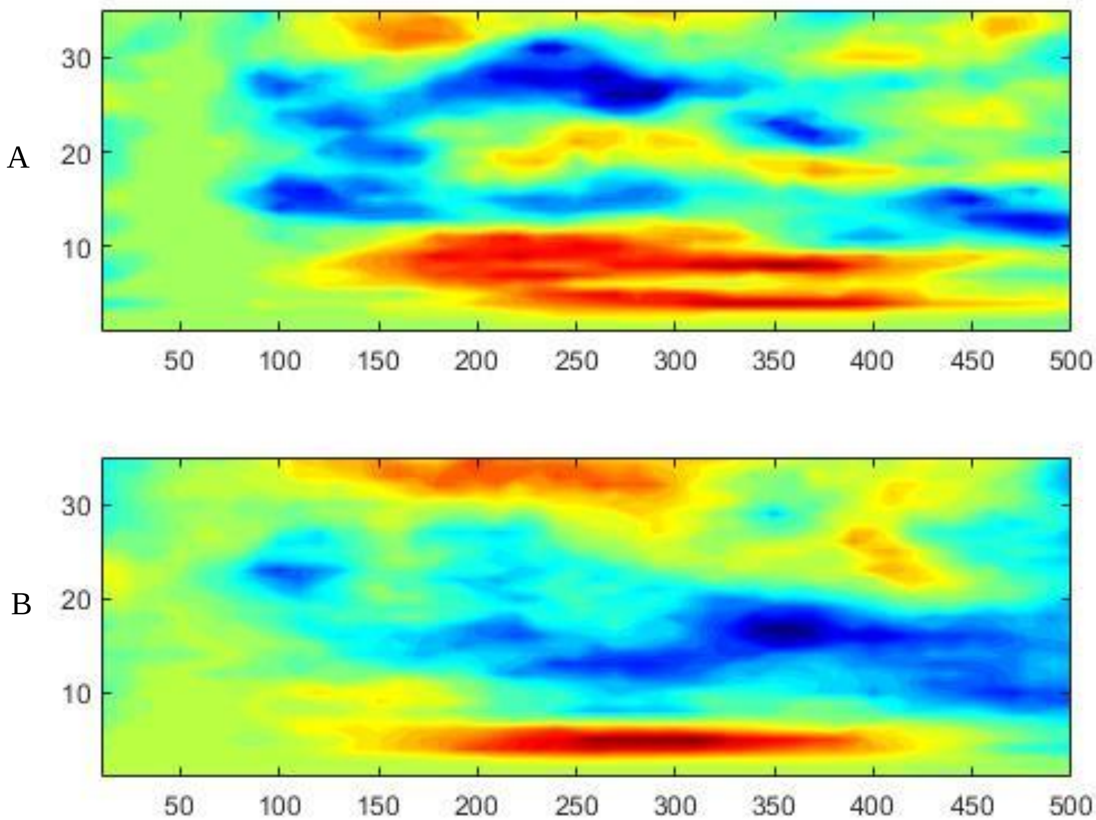

Figure 6 Right frontal brain spectral comparison between concussion (A) and control (B) participants. The images indicate decibel corrected mean event-related changes in spectral power at each time during the epoch at each frequency (1-35 Hz) across time (0-500ms). The blue indicates the lowest power while change of color towards red indicates a gradual increase in power. The green area represents no significant ($p<.05$) change from baseline.

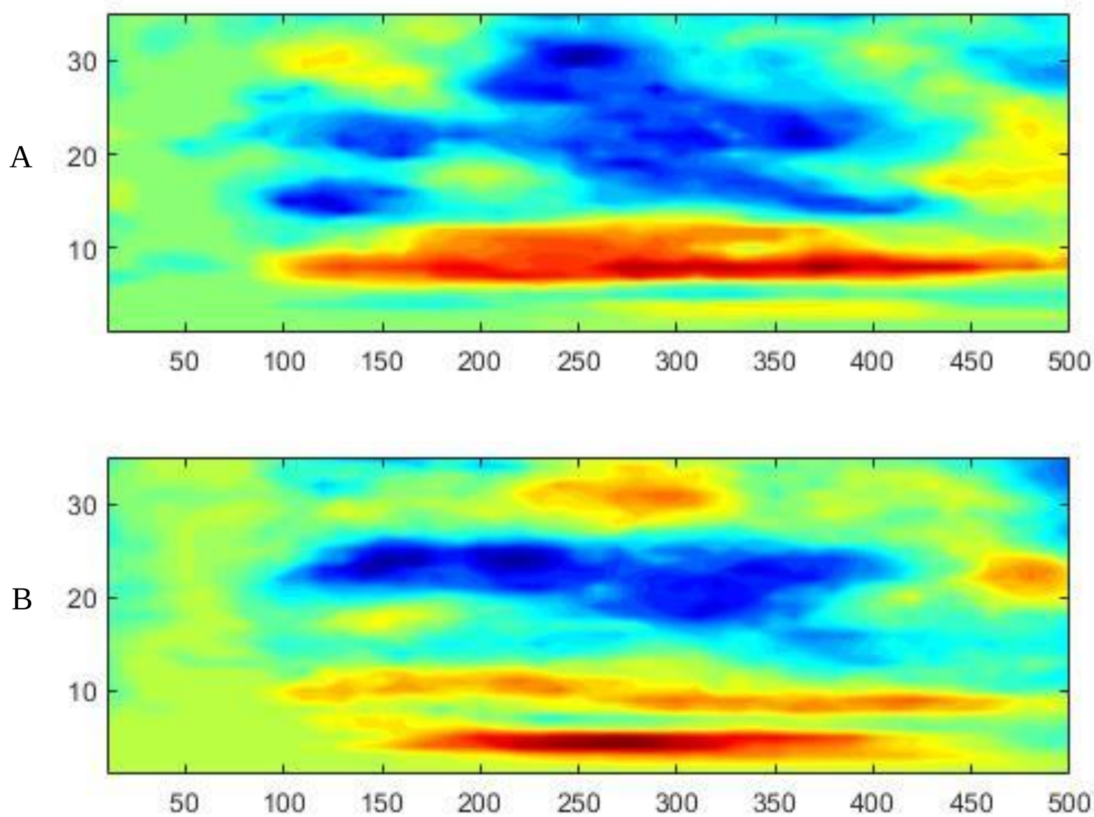

Figure 7 Parietal brain region (P) spectral comparison between concussion (A) and control (B) participants. The images indicate decibel corrected mean event-related changes in spectral power at each time during the epoch at each frequency (1-35 Hz) across time (0-500ms). The blue indicates the lowest power while change of color towards red indicates a gradual increase in power. The green area represents no significant ($p<.05$) change from baseline.

Chapter V. Discussion

Key Findings Related to Study Purpose and Hypotheses

The two aims of this research were to find long term cognitive and psychological deficits due to a concussion in athletes that can lead to an increased risk for further injury to the lower extremities even after the athlete is cleared to return-to-play. As hypothesized, the concussed group indicated mid to low self-efficacy levels after returning to play. A slow reaction time in the concussed group can be related to the differences seen in frequency during the time the participants are reacting to the onset of a target. These differences in frequency can be causing the participants to have a reduction in reaction time since there is more going on in relation to brain activity at the time they are supposed to be responding to stimuli. While the correlation between report of concussion and report of lower extremity injury was not significant, it is clear the long-term effects of concussions are affecting athletes negatively and are causing differences in reaction time and self-efficacy. If the athlete's self-efficacy and reaction time are compromised due to concussion, then it is likely that they will be at an increased risk of lower extremity injury since athletic participation requires physical and mental demands for appropriate sport performance.

Self-Efficacy

The Concussion and Return-to-Play Confidence survey was used for the athletes to rate how or if their confidence in their abilities have changed post injury, if they felt as though they are at the same level of play as they were pre-injury, and other factors that represented their self-efficacy in relation to return-to-play. The findings presented by the survey indicated that players do not feel as though they are psychologically ready to return to play. In fact, only 11.1% of athletes reported that they were confident about playing again. Previous research has connected confidence to performance and found that they have a direct relationship (Skinner, 2013). Since the athletes indicated that were not confident about playing again it is likely that their performance was affected as well. If players perceive themselves to be less competent in their sport it can potentially result in them making riskier decisions or making the wrong decisions due to uncertainty while in play which can become a risk factor for athletes due to the pace of the game and the constant changing environment they are participating in. About half (44.4%) of the athletes indicated that they held back due to fear of reinjury. These results coincide with previous that found fear of reinjury common among athletes who were returning to play (Patel et al., 2019). This can also be relative to lower confidence levels for sport participation and lower confidence in feeling recovered from their concussion enough to return to sport. Since fear of reinjury can manifest in ways like being hesitant and holding back during competitive play, the likelihood of an athlete putting themselves in a situation of further injury increases (Padlog & Eklund, 2007). While the players may have been physically cleared to play, there is clearly still psychological effects occurring regarding the athletes' concussion that is causing differences when compared to athletes who have not received a concussion.

Concussion and Lower Extremity Injury

Deficits to an athlete caused by a concussion can have long-term effects and add risk when the athlete is cleared for return-to-play. One of the main concerns when athletes are cleared is that their deficits will continue to put them in situations that can result in further injury. According to the background questionnaires, there is a significant positive relationship between sport participation and receiving a concussion within a two-year period. This finding adds to previous literature demonstrating the high occurrence of concussions in sports and why further research needs to be completed to investigate the long-term effects of concussions on athletes. Although the relationship between concussions and lower extremity injury is not statistically significant, the data collected from the questionnaires did indicate that some participants who have a history of concussion (even >2 years post injury) report that they have received at least one lower extremity injury in the time after their concussion. This indicates that research on the correlation between these two variables should be used on a larger sample size to distinguish significant relationships and trends. These results are comparable to findings in previous research that indicated athletes who have been cleared to return-to-play show an increased risk of lower extremity injury within a year of a concussive injury (Fino et al., 2019). If the athletes in the current study were measured during a normal sport year, it is likely that lower extremity injury reports would increase as a result of previously concussed athletes returning to play within a year of their most recent concussion.

Oculomotor Performance

Despite the evidence regarding differences in saccadic eye movements between concussed and non-concussed individuals, this research did not indicate any significant differences between the two groups during the GO/NO-GO task. This could be due to the limited sample size of the concussion group (N=5) for the task. Since the current study focused on saccadic eye movement reaction time in relation to a target, it is likely that any saccade error differences between the two groups could have gone undetected. Previous research has indicated that concussed individuals exhibit higher initial saccade error which diminishes the capacity to selectively attend to stimuli as they appear due to larger and longer corrective saccades (DiCesare et al., 2017). Sports require athletes to have accurate fixation and tracking to be able to perform tasks properly and to the best of their ability so it would be beneficial for future research to investigate other factors occurring during saccadic eye movements.

Brain Activity

The results from the EEG data indicated that there were significant differences in the theta, alpha, and beta frequency bands between the concussed participants and the control participants during the beginning of each trial for the GO/NO-GO task. Since the control group is considered to be the healthy model for brain activity in the current study, anything that deviates from the EEG data of the control participants is considered to be a result of a concussive injury The concussed group recruited more spectral power at certain frequencies in the frontal and parietal lobe regions during the task than the control group. This indicated that there were shorter and less frequent instances of ERD for the concussed participants in the left and right frontal regions as their brain is likely compensating for any damage by recruiting additional neuron resources from other brain regions to achieve normal functioning. These findings are similar to previous research that indicated significant differences in spectral frequencies between concussed athletes and matched controls where the concussed athletes had a significant synchronization after stimulus presentation during a visual attentional task (Guay et al., 2017). The right frontal region results show ERS occurring during the theta and alpha frequencies while the control group had ERD occur during a longer period throughout the alpha and beta frequency range. Both groups had similar ERS and ERD patterns in the parietal region indicating that there were no major differences at each frequency during the GO/NO-GO task. Alpha and beta desynchronization have been found to be relative to response preparation in a movement task which is crucial for proper or accurate response (Parlow, Medrano, Seichepine & Ross, 2018; Pfrurtscheller, Neuper & Mohl, 1994). Desynchronization patterns in the control group last over a longer period of time and are more widespread over alpha and beta frequencies compared to the concussed group which could indicate that there are delays occurring in response preparation in concussed individuals which could be leading to a decrease in reaction time. While there is no current research to explain why these frequency differences are occurring in concussed individuals, it can be assumed that these differences are causing changes in the way concussed individuals are processing and reacting to stimuli. The variances in spectral power during certain frequencies between the two groups could help indicate changes in reaction time for the concussed group. These differences could be slowing the stimulus response of the concussed participants since more power in additional neural communication is needed before an appropriate response can be made. This is particularly important since the frontal lobe is responsible for higher level functioning, motor function, problem solving, spatial processing, and judgement while the parietal lobe is responsible for processing and interpreting somatosensory input (Hudac et al., 2017). It is important that these differences are recognized due to the nature of athletics demanding participants to initiate and maintain appropriate performance of dynamic activities in a rapidly changing environment. Without an appropriate reaction to a stimulus in a timely matter, the athletes could be putting themselves in risky positions that could lead to further injury.

Future Directions

Further research is warranted to determine the relationship between concussion and lower extremity injury during a longer period for regular sport participation using a longitudinal study to examine athletes. This would be implemented to follow athletes from their initial concussion to a year out to distinguish what deficits are occurring throughout the time post-concussion and the impact of the deficits on further injury of lower extremities. It would be important to examine this because it is necessary to see if concussion deficits change across time and if their influence on further lower extremity affects athletes long term. This may lead to researchers being able to view a cutoff point as to when athletes no longer suspectable to further injury due to their concussion deficits and could help distinguish a more viable rehabilitation plan for athletes that receive a concussion.

It seems plausible that using more athletes that are involved in a variety of sports could lead to a stronger positive relationship between concussion and lower extremity injury. Thus, future studies should recruit a larger athlete population to examine. It would be beneficial to use a few players from each type of sport, male and female, offered at a university to indicate which athletes are at most risk of future lower extremity injury following a concussion. This could also create more statistically significant findings for the correlation between concussion and lower extremity injury due to having a larger a sample to work with.

Overall, the current study showed that self-efficacy is negatively affected by concussions when athletes are cleared for return-to-play. Future studies may want to examine other forms of efficacy and how they may affect the athlete's confidence when they return-to-play and if it affected the athletes rehabilitation process leading to premature return-to-play and a downplay of persistent concussion symptoms. For example, if the athletes perceived their coaches' attitude about their ability to perform to the same level of sport as they did prior to a concussive injury is negative then the athlete may also not be confident in their own abilities and will not perform appropriately. It could also lead to the athlete returning to play in a shorter period than they should since they do not want their coaches or teammates to view them as a weaker player. Mental toughness is a common theme amongst many athletic teams and can cause a downplay of injury and full recovery. It is important to recognize how outside factors can influence self-efficacy and confidence in these athletes as well when they are returning to play. These factors can truly negatively affect the athlete mentally and physically and can be additional factors that lead to lower levels of self-efficacy and in turn create uncertainty during play.

In order to solve this issue of mid to low self-efficacy during return-to-play after injury that was found in this study, it would be necessary to implement an intervention that includes the four main influences of self-efficacy. Future researchers should use these sources of influence to combat changes in self-efficacy after injury. Since imaginal experiences, verbal persuasion, mastery experiences, and vicarious experiences largely impact one's belief to successfully execute skills and abilities then they can be used to increase self-efficacy following injury and help athletes return to a confidence level that allows them to perform their tasks effectively without creating uncertainty during play that could lead to further injury. For example, imaginal experiences can be used during the rehabilitation process to help build an athlete's confidence by helping them visualize themselves during athletic competition and specific tasks that require them to act appropriately in order to gradually build confidence levels without putting them in actual risk. These four sources of self-efficacy influence can help change the rehabilitation process to cater to psychological aspects of injury.

Limitations

Nevertheless, the study has presented several limitations that should be noted. First, the study population was largely affected due to COVID-19 constraints. Many sports were not able to return until Spring 2021 which created difficulty in recruiting athletes during the fall and early spring. This also added difficulty in finding athletes who had received a concussion or lower extremity injury within a two-year period since many sport teams were not able to practice or compete for about a year during this time. Only five concussed athletes were able to be recruited for aim 2 of the study. In addition, the occurrence of lower extremity injury in participants who had received a concussion could have been affected by these participants being unable to participate in athletic activity due to COVID-19. In other words, it may be likely that lower extremity injury reporting could have been higher if participants were able to fully participate in athletic activity during that time.

Secondly, the study gathered injury information from the participants retrospectively. This could have resulted in the participants underreporting any concussion or lower extremity injury they may have received within the past two years. It also caused many participants to not be able to recall when they received their injury by day/month/year and instead resulted in the participants estimating the month/year of their injury. Many participants also had to estimate the length of time they were unable to participate in athletic activity if their injury was closer to the two-year mark. This could have also caused discrepancies when the participants were filling out the Concussion and Return-to-Play Confidence Survey since their self-efficacy could have increased in the time between them actually returning and taking the survey which would cause the athletes to downplay any initial thoughts they had when returning to their sport.

Thirdly, the survey for lower extremity injury did not require participants to indicate if they received their injury during sport participation. The participants did indicate if they were required to refrain from athletic participation and the length of time they were unable to participate, but it was unclear how the participants were getting injured. This would be important information to be aware of to compare the occurrence of lower extremity injury during sport participation in the concussed participates compared to control participants and investigate differences in injury report between the groups. This could potentially help create a larger gap between injury report as well as tell a story as to what environments the concussed athletes are more vulnerable to further injury in.

Lastly, since the study was split into two separate objectives, we were unable to perform statistical analyses to compare each deficit (self-efficacy, oculomotor performance, reaction time) to the occurrence of a lower extremity injury. Due to this, it cannot be statistically concluded that these factors directly affect an increased risk in lower extremity injury. Instead it can only lead us to assume that the differences in these deficits when comparing concussed and non-concussed individuals have probable cause of increasing risk of lower extremity injury based on the results of the study.

Conclusion

While many concussion studies investigated short-term effects of this injury, this study explored long-term (> 6 months) effects of concussions. The findings show differences in concussed participants greater than ten months after their last concussion which indicates that concussion deficits outlast the acute concussion phase. Since sports demand high levels of attention, confidence, and decision-making, concussed athletes that return-to-play too soon from a concussive injury may not have sufficient cognitive and psychological resources to operate appropriately during sport events, and thus may be at higher risk of further injury. The results of this study suggest that cognitive and psychological effects due to concussion could produce an increased risk for lower extremity injury in athletes. This information indicates that when a concussive injury is physically resolved, it is not resolved cognitively or psychologically. These outcomes can help change the current protocol that is in place for return-to-play following a sports-related concussion as well as expand the rehabilitation process for this injury to cover psychological effects that occur after a concussive injury.

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APPENDIX A: IRB APPROVAL LETTER

EAST CAROLINA UNIVERSITY
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Notification of Amendment Approval

From: Social/Behavioral IRB
To: Caitlin Schult
CC: Nicholas Murray
Date: 4/5/2021
Re: Ame1_UMCIRB 20-002514
UMCIRB 20-002514
An Increase in Lower Extremity Injury as a Result of Cognitive and Psychological Deficits of Concussion

Your Amendment has been reviewed and approved using expedited review on 4/2/2021. It was the determination of the UMCIRB Chairperson (or designee) that this revision does not impact the overall risk/benefit ratio of the study and is appropriate for the population and procedures proposed.

Please note that any further changes to this approved research may not be initiated without UMCIRB review except when necessary to eliminate an apparent immediate hazard to the participant. All unanticipated problems involving risks to participants and others must be promptly reported to the UMCIRB. The investigator must adhere to all reporting requirements for this study.

If applicable, approved consent documents with the IRB approval date stamped on the document should be used to consent participants (consent documents with the IRB approval date stamp are found under the Documents tab in the study workspace).

The approval includes the following items:

Document	Description
email campaign.docx(0.01)	Recruitment Documents/Scripts

For research studies where a waiver or alteration of HIPAA Authorization has been approved, the IRB states that each of the waiver criteria in 45 CFR 164.512(i)(1)(i)(A) and (2)(i) through (v) have been met. Additionally, the elements of PHI to be collected as described in items 1 and 2 of the Application for Waiver of Authorization have been determined to be the minimal necessary for the specified research.

The Chairperson (or designee) does not have a potential for conflict of interest on this study.

IRB00000705 East Carolina U IRB #1 (Biomedical) IORG0000418
IRB00003781 East Carolina U IRB #2 (Behavioral/SS) IORG0000418

APPENDIX B: CONCUSSION AND RETURN-TO-PLAY CONFIDENCE SURVEY

Concussion and Return to Play Confidence Survey

You are being asked to participate in a research study titled "An Increase in Lower Extremity Injury as a Result of Cognitive and Psychological Deficits of Concussion" being conducted by Caitlin Schult, a graduate student at East Carolina University in the Kinesiology Department. This survey will take approximately 10-15 minutes to complete. Your responses will be kept confidential and no data will be released or used with your identification attached. Your participation in the research is voluntary. You may choose to not answer any or all questions, and you may stop at any time. Please call Caitlin Schult at 518-812-5229 or email at schultc19@students.ecu.edu for any research related questions or the University & Medical Center Institutional Review Board (UMCIRB) at 252-744-2914 for questions about your rights as a research participant.

Do you consent to taking this survey?

   a. Yes
   b. No

2. Enter your age.
3. What is your gender identity?
   a. Male
   b. Female
   c. Other
   d. I prefer not to answer
4. Have you ever had a concussion?
   a. Yes
   b. No
5. How many concussions have you had?
6. Was at least one of your concussion sustained during sport participation (e.g recreational, practice, a game)
   a. Yes
   b. No
7. Enter the full date (MM/DD/YYY) of your most recent concussion sustained during sport participation. Estimate if necessary.
8. Which of the following symptoms did you experience while concussed? Circle all that apply.
   a. Headaches

b. Nausea
c. Fever
d. Double or blurry vision
e. Light sensitivity
f. Noise sensitivity
g. Confusion
h. Dizziness
i. Other

9. After your concussion, how long were you unable to fully participate in practice and games? Estimate if necessary (e.g. 3 days, 4 weeks, 2 months)

10. Did you return to play in the same competitive season that you got injured?
    a. Yes
    b. No
11. Which of the following statements best describes you when you returned to play? Circle all that apply.
    a. I was worried about getting re-injured
    b. I was confident about playing again
    c. I doubted that I was fully recovered
    d. I was excited about playing again
    e. I held back to prevent getting re-injured
    f. I was nervous about playing again
    g. I was motivated to play again
12. Did you feel that your reactions were delayed?
    a. Yes
    b. No
13. When returning to play, to what extent were you confident in your abilities to…

7 totally confident (ABSOLUTELY sure I CAN without a doubt)

6 very confident (VERY SURE I CAN)

5 fairly confident (I feel like I CAN)

4 MAYBE I can

3 fairly confident (I have DOUBTS)

2 very unconfident (PRETTY SURE I CAN'T)

1 not confident at all

perform at your previous level of sport performance?

1 2 3 4 5 6 7

play your sport without concern of your concussion?

1 2 3 4 5 6 7

react on time during play?

1 2 3 4 5 6 7

focus on your target during play?

1 2 3 4 5 6 7

Be aware of your surroundings during play?

1 2 3 4 5 6 7

execute the physical skills necessary to succeed?

1 2 3 4 5 6 7

keep mentally focused throughout the competitive event?

1 2 3 4 5 6 7

bounce back from performing poorly to successfully execute your skills?

1 2 3 4 5 6 7

successfully make critical decisions during competition?

1 2 3 4 5 6 7

regain your mental focus after a performance error?

1 2 3 4 5 6 7

effectively use strategy needed to succeed?

1 2 3 4 5 6 7

successfully perform the physical skills required in your sport?

1 2 3 4 5 6 7

maintain the mental focus needed to perform successfully?

1 2 3 4 5 6 7

successfully manage your emotions during competition?

1 2 3 4 5 6 7

overcome problems and setbacks to perform successfully?

1 2 3 4 5 6 7

successfully manage your nervousness so that it doesn't hurt your performance?

1 2 3 4 5 6 7

APPENDIX C: CONCUSSION SURVEY

Age ______________________________

Race: ☐ Caucasian ☐ Afro-American ☐ Hispanic ☐ Asian/Pacific ☐ Alaskan/Indian ☐ Other ________

Sport(s) ______________________________ Position(s) ______________________________

Height ____________ Weight ______________ ☐ Right Handed ☐ Left Handed

Head Injuries / Concussion:

History of Head Injury / Concussion Injury? ☐ YES ☐ NO

- List Dates (month and year, if know)______________________________________

- Please Describe ____

Were Any Diagnostic Tests Performed? ☐ YES ☐ NO (check all that apply)

☐ MRI ☐ CT-Scan ☐ Neuropsychological Testing ☐ Other ______________________

Have You Ever Been Hospitalized, Knocked Out, Become Unconscious, and/or Lost Your Memory Due To A Head Injury / Concussion? ☐ YES ☐ NO

Do You Suffer From Headaches? ☐ YES ☐ NO

- When? ☐ Every Day ☐ 1-2 Times/Week ☐ 1-2 Times/Month
- Where Are Your Headaches Located? ☐ Left Side of Head ☐ Right Side of Head ☐ Front of Head ☐ Back of Head ☐ All Over Your Head

Do You Have A History of Migraine Headaches? ☐ YES ☐ NO

- How Often ________________________ Please Describe __________________

- Medications Taken for Migraines? ______________________________________

Have You Had Headaches For More Than Three (3) Months? ☐ YES ☐ NO

- If yes, please explain ____

Eyes:

Do you routinely wear glasses? ☐ YES ☐ NO

Do you routinely wear contact lenses? ☐ YES ☐ NO

- Prescription?____

APPENDIX D: LOWER EXTREMITY INJURY SURVEY

Age ____________________

Race: ☐ Caucasion ☐ Afro-American ☐ Hispanic ☐ Asian/Pacific ☐ Alaskan/Indian ☐ Other ____________________ Sport(s) ____________________ Position(s) ____________________

Height ____________________ Weight ____________________ ☐ Right Handed ☐ Left Handed

I. Spine / Low Back / Sacroiliac Joint:

Have You Ever Suffered An Injury To Your Spine / Low Back / Sacroiliac Joint? ☐ YES ☐ NO

- List Date(s) / Time (e.g. practices or games) Missed ____________________
- Please Describe ____________________

Were Any Diagnostic Tests Performed? (check all that apply) ☐ X-Rays ☐ MRI ☐ CT-Scan ☐ Bone Scan

Have You Ever Been Hospitalized For A Spine / Low Back / Sacroiliac Joint Injury? ☐ YES ☐ NO

- When? ____________________ Where? ____________________
- Please Describe ____________________

Have You Ever Had Surgery of Any Kind on Your Spine / Low Back / Sacroiliac Joint? ☐ YES ☐ NO

- When? ____________________ Surgeon? ____________________
- Please Describe ____________________

Have You Ever Had Numbness/Tingling Down One (1) or Both Legs? ☐ YES ☐ NO

- Date(s)/Time Missed? ____________________
- Please Describe? ____________________

Have You Ever Been Advised Not To Participate In Athletic Activities Due To A Spine, Low Back, or SI Joint Injury? ☐ YES ☐ NO

- Please Describe ______________________________

II. Hip / Groin:

Have You Ever Suffered An Injury To Your Hip / Groin *(including hernias and/or sports hernias)?* ☐ YES ☐ NO

- List Date(s) / Time (e.g. practices or games) Missed ______________________________
- Please Describe ______________________________

Were Any Diagnostic Tests Performed? (check all that apply) ☐ X-Rays ☐ MRI ☐ CT-Scan ☐ Bone Scan

Have You Ever Had Surgery For A Hip / Groin Injury? ☐ YES ☐ NO

- When? ______________ Where? ______________
- Please Describe ______________________________

Have You Ever Been Advised Not To Participate In Athletic Activities Due To A Hip and/or Groin Injury? ☐ YES ☐ NO

- Please Describe ______________________________

III. Thigh / Hamstring / Quadriceps:

Have You Ever Suffered An Injury To Your Thigh, Hamstring, and/or Quadriceps? ☐ YES ☐ NO

- List Date(s) / Time (e.g. practices or games) Missed ______________________________
- Please Describe ______________________________

Were Any Diagnostic Tests Performed? (check all that apply) ☐ X-Rays ☐ MRI ☐ CT-Scan ☐ Bone Scan

Have You Ever Been Hospitalized For A Thigh, Hamstring, and/or Quadriceps Injury? ☐ YES ☐ NO

- When? ______________ Where? ______________
- Please Describe ______________________________

Have You Ever Had Surgery For A Thigh, Hamstring, and/or Quadriceps Injury? ☐

YES☐ NO

- When? ________________ Surgeon? ________________
- Please Describe ________________

Have You Ever Been Advised Not To Participate In Athletic Activities Due To A Thigh, Hamstring, or Quadriceps Injury?☐

YES☐ NO

- Please Describe ________________

IV. Knee / Patella:

Have You Ever Suffered An Injury To Your Knee and/or Patella (kneecap)? ☐

YES☐ NO

- List Date(s) / Time (e.g. practices or games) Missed ________________
- Please Describe ________________

Were Any Diagnostic Tests Performed? (check all that apply) ☐ X-Rays ☐ MRI ☐ CT-Scan ☐ Bone Scan

Have You Ever Been Hospitalized For A Knee and/or Patella Injury? ☐

YES☐ NO

- When? ________________ Where? ________________
- Please Describe ________________

Have You Ever Had Surgery For A Knee and/or Patella Injury? ☐

YES☐ NO

- When? ________________ Surgeon? ________________
- Please Describe ________________

Have You Ever Been Advised Not To Participate In Athletic Activities Due To A Knee / Patella Injury? ☐

YES☐ NO

- Please Describe ________________

Have You Ever/Do You Presently Wear A Knee Brace? ☐

YES☐ NO

- Which Knee? ______________________ Brand / Model of Brace? ______________________________ __________
- Reason for Wearing ? ____ __________

V. Ankle / Lower Leg:

Have You Ever Suffered An Injury To Your Ankle / Lower Leg? ☐

YES☐ NO

- List Date(s) / Time (e.g. practices or games) Missed ____ __________
- Please Describe ____ __________

Were Any Diagnostic Tests Performed? (check all that apply) ☐ X-Rays ☐ MRI ☐ CT-Scan ☐ Bone Scan

Have You Ever Been Hospitalized For An Ankle / Lower Leg Injury? ☐

YES☐ NO

- When? __________________________________ Where? __________________________________ __________
- Please Describe ____ __________

Have You Ever Had Surgery For An Ankle / Lower Leg Injury? ☐

YES☐ NO

- When? __________________________________ Surgeon? ________________________________ __________
- Please Describe ____ __________

Have You Ever Been Advised Not To Participate In Athletic Activities Due To An Ankle / Lower Leg Injury? ☐

YES☐ NO

- Please Describe ____ __________

Do You Presently ☐ Tape Your Ankle(s) ☐ Use Ankle Brace(s) ☐ Other

- Please Describe ____ __________

VI. Foot / Toes:

Have You Ever Suffered An Injury To Your Foot / Toe(s)? ☐

YES☐ NO

- List Date(s) / Time (e.g. practices or games) Missed ______________________________

- Please Describe ______________________________

Were Any Diagnostic Tests Performed? (check all that apply) ☐ X-Rays ☐ MRI ☐ CT-Scan ☐ Bone Scan

Have You Ever Had Surgery For A Foot / Toe Injury? ☐

YES☐ NO

- When? ____________________ Surgeon? ____________________

- Please Describe ______________________________

Have You Ever Been Advised Not To Participate In Athletic Activities Due To An Foot and/or Toe Injury? ☐

YES☐ NO

- Please Describe ______________________________